Structural Features and Biological Activities of Bioactive Compounds from *Fortunella margarita* (Lour.) Swingle: A Review

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ABSTRACT *Fortunella margarita* (Lour.) Swingle, commonly known as kumquat, is the smallest citrus fruit. It thrives in southeastern China and is widely cultivated and consumed in the world due to its multiple health benefits. It has been used as an important herbal medicine in traditional Chinese medicine and also as one of the most popular fruits. There are various kinds of bioactive compounds in *F. margarita*, such as polysaccharides, limonoids, essential oils, flavonoids, phenolic acids, vitamins, dietary fiber, etc. In addition, many studies have reported that these bioactive compounds can be used as antioxidant, antimicrobial, hypolipidemic, drosophila lure components in functional foods, pharmaceuticals and daily chemical products due to their biological activities. This review focuses on the structural features and biological activities of polysaccharides, limonoids, essential oils and flavonoids and other bioactive substances from *F. margarita* and their potential applications in food, daily chemical and pharmaceutical industries.

Keywords: *Fortunella margarita* (Lour.) Swingle; bioactive compounds; structural features; biological activities; application; DOI: 10.14102/j.cnki.0254-5861.2011-1788

1 INTRODUCTION

Fortunella margarita (Lour.) Swingle, known as kumquat or cumquat, originates in the southeastern China and is grown for its delicious fruit in many parts of the world, including Europe, Japan, USA, Puerto Rico, Guatemala, Suriname, Colombia, Brazil,

Australia, South Africa and India[1]. It is the smallest citrus fruit and is distinguished by the fact that it can be eaten completely, including the peel[2]. *F. margarita* is the characteristic fruit resource in China and is widely cultivated in Fujian, Zhejiang, Jiangxi, Hunan and Guangxi provinces[3]. In 2015, its production is over 500,000 tons in China and its output value is up to 10 billion[4]. It is highly nutritious and contains a lot of bioactive compounds, such as polysaccharides, limonoids, essential oils, flavonoids, phenolic acids, vitamins, dietary fiber, amino acids, etc.[5, 6]. *F. margarita* has been used to prevent the rupture of blood vessels, reduce the fragility and permeability of blood capillaries and slow the hardening of arteries[7]. Furthermore, it is used in traditional herbal medicines, especially for the treatment of coughs and colds[8].

The biological activities of *F. margarita* are closely related to its sufficient bioactive compounds. Zeng et al.[9] reported the antimicrobial activities of *F. margarita* were concerned with its polysaccharides. Its polysaccharide fractions also displayed antioxidant activities, pancreatic lipase inhibitory effect and bile acid-binding activities[10]. Different polysaccharide fractions had various structural features, which resulted in the differences of biological activities. Limonin and nomilin were the main components of the limonoids from *F. margarita* and their antioxidant activities were investigated by Meng[11]. Essential oils from *F. margarita* peel and seed were determined by the previous literatures[12, 13]. These oils displayed different chemical components and biological activities. Zheng et al.[14] and Li et al.[15] investigated the chemical components and the functional properties of flavonoids from *F. margarita*. In addition, the structural characteristics and functional activities of other bioactive compounds from *F. margarita* were also studied by some literatures, such as phenolic acids, vitamins, dietary fiber, amino acids and minerals[16]. All of these bioactivities had something to do with the chemical components and molecular structural features of the bioactive compounds. These basic scientific studies make it possible that the bioactive compounds from *F. margarita* are utilized as active ingredients in food, pharmaceutical and daily chemical industries.

The objective of the review was to generalize and summarize the information of bioactive compounds from *F. margarita*. To generate summary tables and figures, the bioactivities and chemical structures of bioactive compounds were provided by the original papers. Moreover, the potential applications of bioactive compounds as ingredients in food, daily chemical and

pharmaceutical industries were discussed.

2 CHEMICAL COMPOSITION

F. margarita is highly nutritious, containing a variety of bioactive compounds, such as non-starch polysaccharides, essential oils, limonoids, flavonoids, etc. Table 1 exhibits the chemical composition of *F. margarita*. Some data are provided by USDA Food Composition Databases. It contains 80.85 g of water, 1.88 g of protein, 0.86 g of total lipid, 0.52 g of ash, 15.9 g of carbohydrate, 6.5 g of fiber, and 9.36 g of sugars per 100 g of edible portion[17]. And it is also rich in minerals, vitamins, carotene, cryptoxanthin, lutein, zeaxanthin, and so on. *F. margarita* displays the multiple health benefits due to its various bioactive compounds. Several studies have reported that the hypocholesteremic and hypolipidemic effect of citrus fruits were attributed to their polysaccharides[18]. Pectic polysaccharides from citrus fruits inhibited the activity of lipase[19]. Additionally, the glycemic index was regulated by feeding kumquat juice in mice, which was related to its flavonoid compounds.

3 POLYSACCHARIDES

3. 1 Structural properties

Polysaccharides, as the main bioactive compounds from *F. margarita*, approximately accounted for 12% of dried *F. margarita*[4]. The yield of polysaccharides from *F. margarita* (FMPS) was up to 9.15 ± 0.13% by ultrasonic-microwave synergistic extraction method[20], which was increased by 405.52%, 128.18% and 76.64% compared to hot water extraction[21], ultrasonic-assisted extraction[22] and microwave-assisted extraction[9] methods, respectively. FMPS was a macromolecular heteropolysaccharide, containing four kinds of polysaccharide fractions with different concentrations and molecular weights[10]. Size exclusion chromatography, ultrafiltration, and antisolvent precipitation are the primary methods for the fractionation of macromolecular polymers. The chromatography is a more accurate method for purifying and isolating polysaccharides as compared to ultrafiltration and antisolvent precipitation methods. From Fig. 1, four polysaccharide fractions, named as FMPS1, FMPS2, FMPS3 and FMPS4, were isolated

orderly by DEAE Sepharose CL-6B column and Sephadex G-100 gel column[10].

Different polysaccharides had variously structural properties. There are also some different structures between crude and purified polysaccharides[23]. The purified polysaccharide molecules aggregated in the solution by confocal laser scanning microscopy (CLSM) (Fig. 2). The polysaccharide network of purified FMPS was observed and unevenly distributed in the medium and the shape of aggregation was compact and smooth while the molecules of the crude FMPS dispersed in the solution system and there was no network structure. The structural features were also affected by the extraction method. Zeng et al.[24] investigated the effects of different extraction methods on the molar mass distribution and chain conformation of polysaccharides of *F. margarita*. They found that ultrasonic-assisted and microwave-assisted extraction methods had a significant degradation effect on the molar mass of polysaccharides, while ultrasonic microwave synergistic extraction method had no influence upon the polysaccharides.

Detailed structural features of various polysaccharides are shown in Table 2. All of the polysaccharides had the monosaccharide composition of galactose, galacturonic acid and mannose. FMPS1 and FMPS2 had glucose, and FMPS2 and FMPS3 had arabinose while FMPS1, FMPS3 and FMPS4 had rhamnose[10]. Moreover, the relative molar percentage of their monosaccharide composition was different. The molecular weights of FMPS, FMPS1, FMPS2, FMPS3 and FMPS4 were 6.192×10^6 (±2.59%), 2.572×10^7 (±0.517%), 1.755×10^6 (±2.009%), 2.563×10^5 (±1.784%) and 2.411×10^5 (±1.808%), respectively[24]. FMPS3 and FMPS4 had similar molecular weight, indicating these fractions were not isolated easily by ultrafiltration and antisolvent precipitation[24]. The glycosidic linkages of FMPS and FMPS3 were mainly β-glycosidic with a small amount of α-glycosidic bonds, while FMPS1 and FMPS2 were mainly α-glycosidic with a small amount of β-glycosidic bonds, as well as FMPS4 was only β-glycosidic linkage. The chain conformation of the polysaccharides in aqueous solution varied. FMPS1 had a tight uniform spherical conformation, FMPS2 had a random coil conformation, whereas FMPS, FMPS3 and FMPS4 displayed highly branched structures.

3. 2 Biological activities

Polysaccharides from many species of plants have important roles in cell-cell communication, cell adhesion and molecular recognition in the immune system[25]. They have some biological activities, including antioxidant activity, antitumor activity,

hypoglycemic effects, antilipidemic functions, anticancer activity, radioprotection, etc[4]. The biological activities of polysaccharides from *F. margarita* are shown in Table 2. FMPS displayed antioxidant and antibacterial activities. Zeng et al.[9] reported FMPS displayed a good antibacterial effect on *Staphyloccocus aureus Rosenbach*. The minimal inhibitory concentrations of polysaccharide against *Staphyloccocus aureus Rosenbach*, *Salmonella*, *Escherichia coli*, *Bacillus subtilis* and *Pseudomonas* were 3.13, 50.00, 12.50, 12.50 and 12.50 mg/mL, respectively. FMPS had a certain capacity on scavenging hydroxyl, superoxide and DPPH radicals, and the antioxidant activities increased with the increasing concentration[24]. Among these four fractions, FMPS1 and FMPS3 had stronger inhibitory effects on pancreatic lipase, and FMPS1 and FMPS2 had stronger bile acid-binding abilities, as well as FMPS3 and FMPS4 exhibited greater scavenging activities against hydroxyl, superoxide and DPPH radicals[10].

Moreover, the effects of FMPS on the serum lipid level and antioxidant index of plasma and tissues were investigated in the hyperlipidemia rats[4]. The result showed the contents of TG, TC, LDL-C and NEFA reduced and HDL-C and LIPA increased significantly by feeding FMPS in the hyperlipidemia rats. Meanwhile, the abilities of SOD, GSH-Px, GST and T-AOC enhanced and the content of MDA reduced by feeding FMPS in the hyperlipidemia rats. There was a certain concentration-response relationship. Moreover, the body weight, liver and spleen index of the hyperlipidemia rats reduced significantly, which was relative to the concentration of FMPS. Histopathological micrographs of hepatic tissue and blood vessel morphology of the hyperlipidemia rats showed the fat deposition in liver cells was reduced and the vascular endothelial cells were protected by feeding FMPS in the hyperlipidemia rats. The result indicated FMPS displayed significant regulatory role on the lipid metabolism disorder of the hyperlipidemia rats. Combination with the hypilipidemic effect *in vitro*, the hypolipidemic mechanism of polysaccharides from *F. margarita* in the hyperlipidemia rats was achieved by increasing the lipase activity, reducing the content of lipid and enhancing the activity of antioxidant enzymes.

3. 3 Structure-bioactivity relationship

The hypolipidemic mechanism, including inhibiting the pancreatic lipase activity, binding bile acid and antioxidant activity, was affected by the preliminary structural characteristics of polysaccharide fractions from *F. margarita* (Fig. 1). The inhibitory effects on pancreatic lipase activity were affected by the monosaccharide composition of the polysaccharide fractions,

especially the pectic polysaccharides[26]. The ability of polysaccharides to bind bile acid might be related to their anionic, cationic, physical properties, monosaccharide composition and molecular weight[27]. Glucan could effectively bind bile acids through the molecular interactions with bile salts, and the high viscosity of the polysaccharides had hydrodynamic restrictions on bile acid-binding[28]. Several factors affected the antioxidant activities of the polysaccharides, including their monosaccharide composition, glycosidic linkage, molecular weight and chain conformation[29]. FMPS3 were mainly pectic polysaccharides with appropriate molecular weight, β-glycosidic linkage and highly-branched chain conformation in aqueous solution.

4 LIMONOIDS

4. 1 Structural features

Limonoids are a class of highly oxidized triterpenes of secondary metabolites. Limonoids exist in the form of a free ligand and a sugar ligand in citrus fruits, especially fruit peel and seed. At present, more than 300 limonoids have been found, the representatives of which are limonin and nomilin. The acidic limonoids are soluble in water, in which, however, the neutral one is not easy to dissolve[14]. Limonoids are the main substances that cause bitter taste of citrus fruit juice. The extraction, purification, isolation and structural property of limonoids from *F. margarita* were studied by Meng[11]. The extracts by supercritical carbon dioxide method were isolated and purified by the recrystallization method. Two crystals were obtained and the molecular structure contained olefin, lactone, vinyl ether, epoxy compounds and groups of $-CH_2-$ and $-CH_3$ by FT-IT and NMR. The chemical structures of the crystals were characterized by ^{1}D NMR, ^{2}D NMR and LC-MS/MS[11]. It was found that the limonoids from *F. margarita* were composed of limonin and nomilin. The fragment analysis of limonin and nomilin from *F. margarita* by secondary mass spectrometry are shown in Tables 3 and 4. These chemical structures were in agreement with the standard substances. And the content of limonin from *F. margarita* was higher than that of nomilin, consistent with the results by Zheng et al.[14].

4. 2 Biological activities

Limonoids from *F. margarita* are the main active ingredients of anti-cancer. Moreover, they have the activities of anti-inflammatory, anti-anxiety, sedation, regulating cholesterol and

preventing atherosclerosis (Fig. 3)[30]. They have been used as ingredients in food and pharmaceutical industries due to the health benefits. Li et al.[31] reported the limonoids from *F. margarita* had the inhibitory effect on DNA oxidation. And the limonoids could reduce the oxidizing reaction of lard and affected the oxidizing rate[11]. These limonoids had strong antibacterial activities against *Bacillus subtilis*, *Staphylococcus aures*, *Escherichia coli*, *Aspergillus niger*, *Shigella*, *Salmonella*, and *Saccharomyces cervisiae*. The minimum inhibition concentrations were 1.25, 1.25, 1.25, 2.50, 2.50, 2.50 and 5.00 mg/mL, respectively. The acidic condition could promote their antibacterial activities[11]. Murthy et al.[32] reported that limonin and limonin glycosides inhibited the proliferation of human colon cancer cells. Patil et al.[33] studied the anticancer activities of five purified limonoids. Studies had shown that it had a significant inhibition of pancreatic cancer cells, which was consistent with Zhang's research[34]. It is reported by Hafeeze et al.[35] that the limonoids had insecticidal effect and resistance capacity to aedes.

5 ESSENTIAL OILS

5.1 Chemical components

Essential oils are aromatic and volatile liquids extracted from various plant as secondary metabolites. *F. margarita* peel and seed contain a large number of oil cells which contain pigment and aromatic oil. When they get ripe, the content of the essential oil from *F. margarita* peel is generally 22%～28%[36]. The aromatic oil has great quality, which is an important and popular natural chemical raw material and edible flavor. The peel essential oil can be extracted by the methods of squeezing, hydro-distillation, oil separation, carbon dioxide extraction and continuous subcritical water extraction. The essential oils from *F. margarita* peel were extracted by microwave, ultrasonic and supercritical CO_2 fluid methods, and the highest yield was up to 5.08%. The physicochemical properties of the peel essential oil were as follows: 0.4668 of acid value, 4.2456 of ester value, 0.8380 g/mL of density, 1.4707 of diopter, and 1.8920 of optical rotation[37]. The component analysis of peel essential oil was studied by Wang et al.[38]. There are 88 components in peel essential oil, including alkanes, alkenes, alcohols, acids, ketones, aldehydes and ester substances. Essential oils from *F. margarita* peel were mainly composed of D-limonene, myrcene and β-pinene with relative amounts of 72.90%, 6.88% and 3.60%[13].

Moreover, the physicochemical properties and chemical components of seed oil from *F. margarita* were investigated by Xie et al.[13]. The physicochemical properties were as below: 200.00 ± 3.45 of saponification value, 130.12 ± 2.67 of iodine value, 1.47 of refractive index, 0.92 of proportion, 1.58 ± 0.06 of acid value and 5.02 ± 0.14 of peroxide value. The chemical components were also detected by GC-MS. The main components were linoleic acid (47.82%), oleic acid (17.06%) and methyl palmitate acid (15.88%)[39]. The unsaturated fatty acid was up to 64.88%. Its linoleic acid content was generally higher as compared to the rapeseed oil, linseed oil, peanut oil and sesame oil.

5. 2 Biological activities

The biological activities of essential oils from *F. margarita* peel and seed are shown in Fig. 4. The antimicrobial activities of peel essential oil showed that it had the inhibiting effect against *staphylococcus aureus*, *escherichia coli*, *salmonella*, *aspergillus niger* and *yeast*. The inhibiting effect was promoted by adding some acid solution, but the antimicrobial activities had thermal instability[12]. The peel essential oil displayed the effectively antioxidant activity in edible fat, especially in olive and lard oils. The peroxide values of olive and lard oils decreased with the addition of peel essential oil[38]. Interestingly, the peel essential oil had great drosophila lure effect by Wang et al.[38]. When the test time was 40 min, 10 μL/mL of peel essential oil displayed the strongest drosophila lure effect and the luring rate was up to 81.0%. It can be used as a potential attractive substance in agriculture. In addition, its seed oil displayed strong scavenging abilities against hydroxyl and superoxide radicals and had the great total antioxidant activity. The scavenging ability against hydroxyl radical was stronger as compared to V_c[12].

6 FLAVONOIDS

6. 1 Chemical components

Flavonoids are plant secondary metabolites and exist in higher plants. Flavonoids usually exist in the form of aglycon and glycosides (one or more glycosyl groups on the ring). Flavonoids are widely found in the peel and pulp from *F. margarita*. Zheng[14] used UPLC-PDA-MS to determine the content of 9 flavonoid compounds, such as apigenin 8-C-rutinoside, hesperidin, neohesperidin, rhoifolin, poncirin, acacetin 7-O-rutinoside, phloretin, phloretin 3′,5′-di-C-*β*-glycopyranoside,

apigenin, acacetin 8-C-neohesperidoside and acacetin 6-C-neohesperidoside. It was found that phloretin 3′,5′-di-C-*β*-glycopyranoside was the main component of flavonoids from *F. margarita*. Acacetin 3,6-di-*C*-glucoside, vicenin-2, lucenin-2,4′-methyl ether, narirutin 4′-*O*-glucoside and apigenin 8-*C*-neohesperidoside were identified for the first time in kumquat juice by Barreca et al.[40]. According to literatures, the flavonoids from *F. margarita* were mainly composed of rhoifolin, phloretin 3′,5′-di-C-glucoside, vicenin-2, narirutin 4′-O-glucoside, acacetin 8-C-neohesperidoside, and didymin (Fig. 5)[41]. These main components affected the biological activities of lavonoids from *F. margarita.*

6. 2 Biological activities

Flavonoids have an important health effect on the human body. Studies have shown that flavonoids have good antioxidant activity, cardiovascular disease prevention, anti-cancer activity, anti-inflammatory, antibacterial activity, antiviral activity, free anticoagulant, antithrombotic, etc.[42]. Li et al.[43-45] reported that flavonoids from *F. margarita* had significant antioxidant effects and promoted the immune function of mice, as well as significantly relieved symptom of diabetes in mice. Chen et al.[46] reported that the total flavonoids could protect the liver of acute alcoholism of mice. Antioxidant tests of flavonoids from kumquat showed that the inhibition rates of flavonoids against DPPH ·and ABTS ·were up to 79% and 93%, respectively[40].

7 OTHER BIOACTIVE COMPOUNDS

In addition to polysaccharides, limonoids, essential oils and flavonoids, *F. margarita* is also rich in phenolic acids, vitamins, dietary fiber and other bioactive substances. Phenolic acid is a compound in form of the same benzene ring with a number of phenolic hydroxyl groups. It is an important secondary metabolite in the plant, which is the second major metabolite of the plant followed by the flavonoids. Most of the phenolic acids in *F. margarita* are the hydroxylated derivatives of cinnamic and benzoic acids[47]. The coumaric, chlorogenic, caffeic, erucic and ferulic acids from *F. margarita* in Taiwan were determined using HPLC by Wang et al.[48]. They found the ferulic and erucic acids were the most important soluble phenolic acids in *F. margarita* peel. Some studies had shown that *F. margarita* phenolic acids had various biological activities, such as anti-virus, anti-inflammatory, anti-allergy, immune function antibacterial activity, pest

control effect, etc. *F. margarita* peels contained the high total amounts of lutein, zeaxanthin, β-cryptoxanthin and β-carotene, which exhibited antioxidant activity, anti-cancer activity, enhancing immune function, preventing osteoporosis, preventing night blindness, preventing cardiovascular disease, anti-aging activity, inhibiting tumor cells growth, and so on[48]. *F. margarita* also contained a certain amount of dietary fiber, which could increase the activity of metabolic granules in order to prevent constipation[16].

8 APPLICATIONS

So far, *F. margarita* is mainly used as an edible fresh fruit and is rarely processed for products. Its products only contain fruit juice, concentrated juice, jam, wine, vinegar, dried fruit, etc. The comprehensive development and utilization of bioactive compounds from *F. margarita* have become an important direction for the future development of *F. margarita* industry, especially polysaccharides, limonoids, essential oils and flavonoids. FMPS and FMPS3 can be used as novel natural hypolipidemic and antioxidant agents in food industry, respectively. The limonoids and flavonoids can be utilized as natural antibacterial and antioxidant agents in functional food and pharmaceutical industry, respectively. The essential oils have been developed as raw materials in Chinese daily chemical industry, such as sunscreen, skin cream, hand cream and soap.

9 CONCLUSION

In this review, when going through the literatures, it was observed that there are sufficient amount of bioactive compounds in *F. margarita*. The structural features of bioactive compounds contributed to their biological activities. The polysaccharide was a macromolecular heteropolysaccharide, containing four kinds of polysaccharide fractions with different molecular weight. Different polysaccharide fractions displayed antibacterial, antioxidant activities and hypolipidemic effect. The limonoids were composed of limonin and nomilin, which had anti-cancer activity, anti-inflammatory activity, anti-anxiety activity, sedation effect, cholesterol regulation and prevention atherosclerosis. Essential oils from *F. margarita* peel were mainly

composed of D-limonene, myrcene and *β*-pinene while linoleic acid, methyl palmitate and oleinic acid were the major components of *F. margarita* seed oils. Essential oils displayed the antimicrobial, antioxidant activities and drosophila lure effect. The flavonoids were mainly composed of vicenin-2, narirutin 4′-O-glucoside, phloretin 3’,5’-di-C-glucoside, rhoifolin, acacetin 8-C-neohesperidoside, didymin, which had a strong capacity to eliminate free radicals. Therefore, evidence suggests that bioactive compounds from *F. margarita* have potentials as active ingredients for preparing various functional foods, pharmaceutical and daily chemical products due to their valuable biological functions and beneficial health effects.

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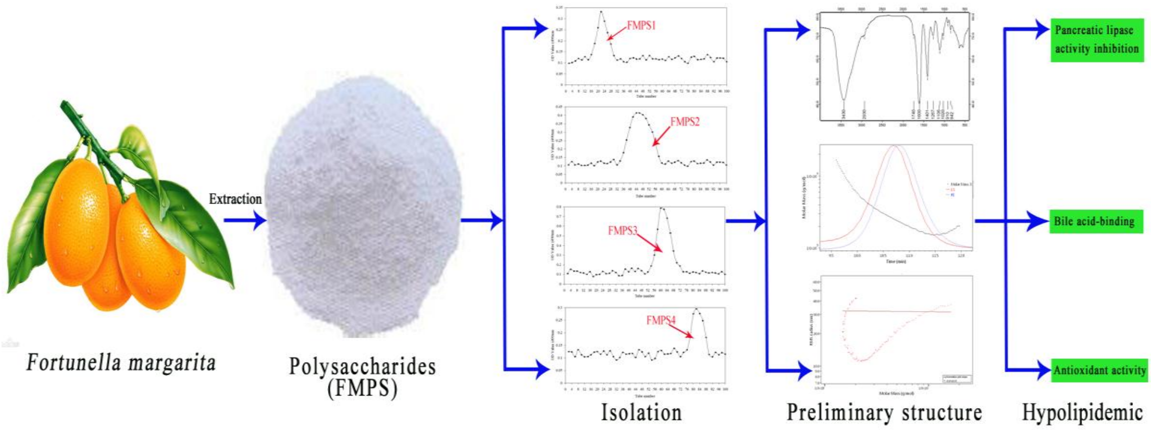


Fig. 1. Structural characterization and hypolipidemic effect of polysaccharide fractions from *F. margarita*[10]. Reprinted with permission

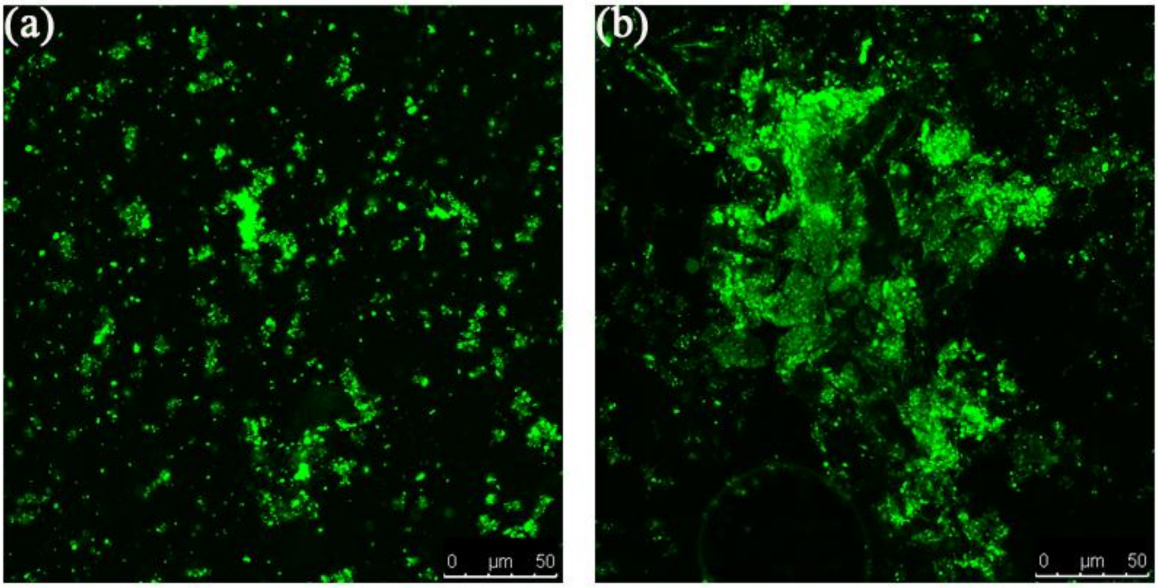


Fig. 2. CLSM images of FMPS solutions: (a) Crude FMPS; (b) Purified FMPS[23]. Reprinted with permission

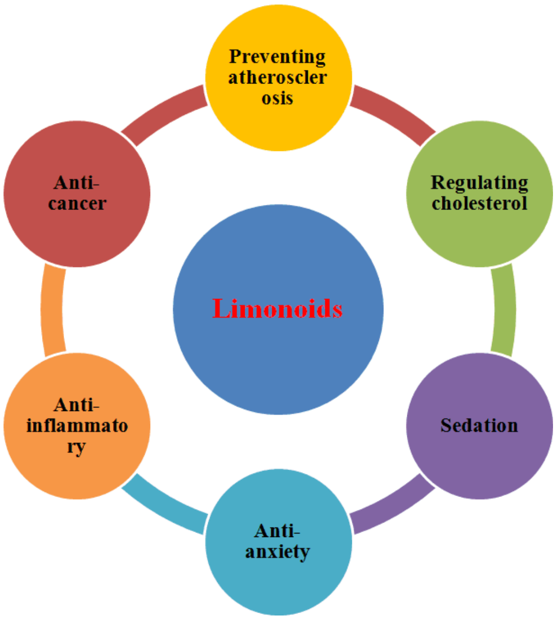


Fig. 3. **Biological activities of Limonoids from *F. margarita***

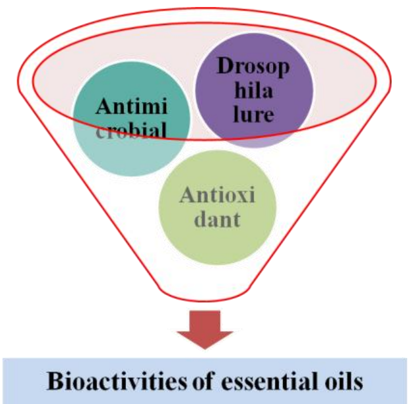


Fig. 4. **Biological activities of essential oils from *F. margarita***

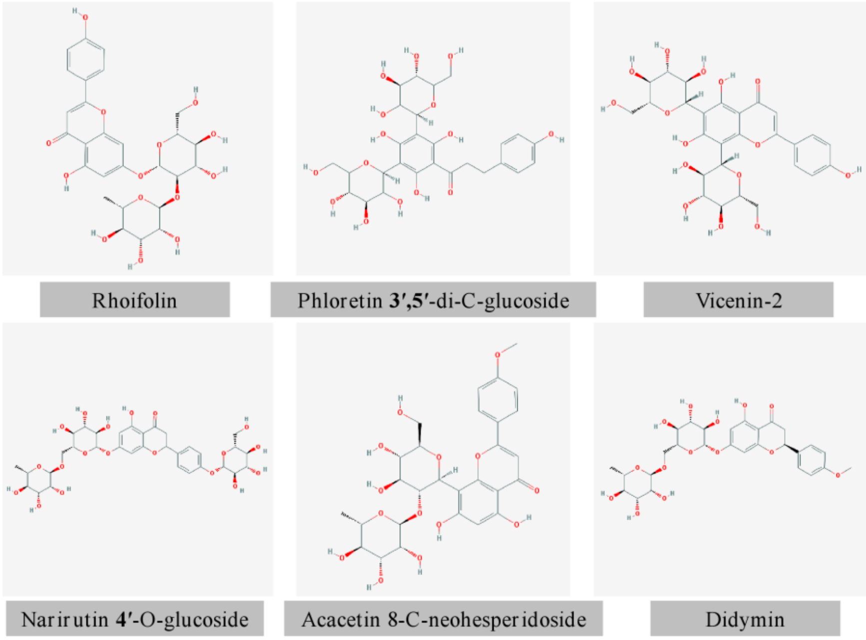


Fig. 5. Chemical components of flavonoids from *F. margarita*

Table 1. Chemical Composition of *F. margarita*

Nutrient	**Units**	**Value per 100 g of edible portion**
Water	g	80.85
Protein	g	1.88
Total lipid (fat)	g	0.86
Ash	g	0.52
Carbohydrate	g	15.9
Fiber, total dietary	g	6.5
Sugars, total	g	9.36
Minerals		
Calcium, Ca	mg	62
Iron, Fe	mg	0.86
Magnesium, Mg	mg	20
Phosphorus, P	mg	19
Potassium, K	mg	186
Sodium, Na	mg	10
Zinc, Zn	mg	0.17
Copper, Cu	mg	0.095
Manganese, Mn	mg	0.135
Vitamins		

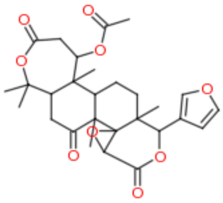
Vitamin C	mg	43.9
Thiamin	mg	0.037
Riboflavin	mg	0.09
Niacin	mg	0.429
Pantothenic acid	mg	0.208
Vitamin B-6	mg	0.036
Folate, total	mcg	17
Folate, DFE	mcg_DFE	17
Vitamin A, IU	IU	290
Vitamin A, RAE	mcg_RAE	15
Vitamin E	mg	0.15
Lipids		
Fatty acids, total saturated	g	0.103
Fatty acids, total monounsaturated	g	0.154
16:1 undifferentiated	g	0.021
18:1 undifferentiated	g	0.137
Fatty acids, total polyunsaturated	g	0.171
18:2 undifferentiated	g	0.124
18:3 undifferentiated	g	0.047
Other		
Carotene, alpha	mcg	155
Cryptoxanthin, beta	mcg	193
Lutein + zeaxanthin	mcg	129

Table 2. Structural Features and Biological Activities of Polysaccharides

Component name	Monosaccharide composition	Molecular weight (Da)	Glycosidic linkage	Chain conformation	Biological activities	References
FMPS		6.192×10^6 (±2.59%)	β-glycosidic with a small amount of α-glycosidic bonds	Highly dispersive large polymer	Antioxidant activities. Antibacterial activities	[4, 8, 9, 23]
FMPS1	Galactose, glucose, galacturonic acid, rhamnose and mannose	2.572×10^7 (±0.517%)	α-glycosidic with a small amount of β-glycosidic bonds	Tight uniform spherical conformation	Pancreatic lipase active inhibition. Bile acid-binding	[4, 10]

					abilities	
FMPS2	Galactose, glucose, galacturonic acid, arabinose and mannose	1.755×10^6 (±2.009%)	*α*-glycosidic with a small amount of *β*-glycosidic bonds	Random coil conformation	Bile acid-binding abilities	[4, 10]
FMPS3	Galactose, galacturonic acid, arabinose, rhamnose and mannose	2.563×10^5 (±1.784%)	*β*-glycosidic with a small amount of *α*-glycosidic bonds	Highly branched polymers	Pancreatic lipase active inhibition. Antioxidant activities	[4, 10]
FMPS4	Galactose, galacturonic acid, rhamnose and mannose	2.411×10^5 (±1.808%)	*β*-glycosidic linkage	Highly branched polymers	Antioxidant activities	[4, 10]

Table 3. Fragment Analysis of Limonin from *F. margarita* by Secondary Mass Spectrometry[11]. Reprinted with Permission

Order	Mass charge ratio (m/z)	MS/MS Fragment	Fragment ions affiliation	Structural formula
1	515.2274	$C_{28}H_{35}O_9$	$[M+H]^+$	

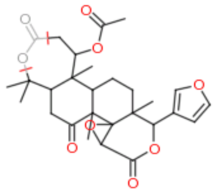
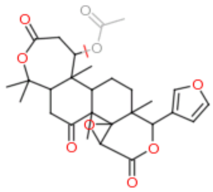
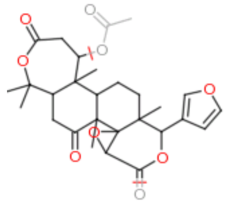
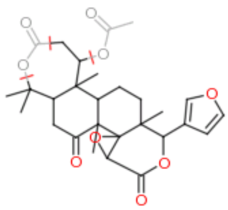
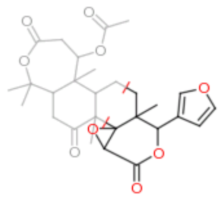
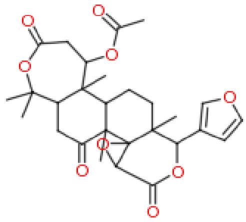
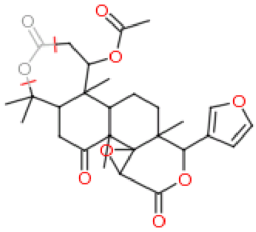
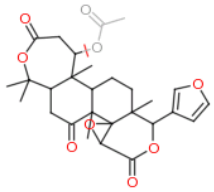
2	469.2205	$C_{27}H_{33}O_7$	$[M+H-CH_2O_2]^+$	
3	455.2080	$C_{26}H_{31}O_7$	$[M+H-C_2H_4O_2]^+$	
4	437.1967	$C_{26}H_{29}O_6$	$[M+H-C_2H_6O_3]^+$	
5	411.2166	$C_{25}H_{31}O_5$	$[M+H-C_3H_4O_4]^+$	
6	205.0513	$C_{11}H_9O_4$	$[M+H-C_{17}H_{26}O_5]^+$	

Table 4. Fragment Analysis of Nomilin from *F. margarita* by Secondary Mass Spectrometry[11]. Reprinted with Permission

Order	Mass charge ratio (m/z)	MS/MS Fragment	Fragment ions affiliation	Structural formula

1	471.2020	$C_{26}H_{31}O_8$	$[M+H]^+$	
2	453.1904	$C_{26}H_{29}O_7$	$[M+H-H_2O]^+$	
3	425.1966	$C_{25}H_{29}O_6$	$[M+H-C_2H_4O_2]^+$	

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This review focuses on the structural features and biological activities of polysaccharides, limonoids, essential oils and flavonoids and other bioactive substances from *F. margarita* and their potential applications in food, daily chemical and pharmaceutical industries. The polysaccharides were a macromolecular heteropolysaccharide, containing four kinds of polysaccharide fractions with different molecular weights. Different polysaccharide fractions displayed antibacterial, antioxidant activities and hypolipidemic effect. This functionality was affected by the monosaccharide composition, glycosidic linkage, molecular weight and chain conformation in aqueous.